Review Article

Groundwater Flow Modelling for Selected Parts of Port- Harcourt and Obi-Akpo Local Government Areas in Rivers State, Nigeria

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ABSTRACT

Aim: There is need to develop steady and transient state models for the hydro-geological system of Port Harcourt and Obio-Akporareas to understand the groundwater system of the area

Study design: Port Harcourt and Obio-Akpor.

Place and Duration of Study: Port Harcourt and Obio-Akpor, between April 2011 and April 2021.

Methodology: Thirty-eight boreholes were selected randomly within the studied areas and examined to obtain their physcio-chemical properties which include borehole locations, chemical properties, water level, discharge, aquifer transmissivity, specific yield and storativity. The data obtained were used to develop base map for groundwater model. A mathematical model (MM) was developed from estimated initial conditions (hydraulic conductivity and recharge). The MM model was excited and its response was used to derive a Modular Three-Dimensional Finite Difference ground water flow model. Groundwater Modelling System version 10.06 software was used to simulate and predict the groundwater flow. The sensitivity of the model was determined by comparing computed and observed hydraulic heads using Root-Mean-Square-Error.

Results: The mean values of aquifer transmissivity, specific yield and storativity from the field data were 0.0600m²/min; 0.11596m³/min and 0.00040, respectively. The developed base map spread between 4.4601ºN, 7.0498ºE and 4.8156ºN, 7.5098ºE. The estimated hydraulic conductivity and recharge were 0.00004m/day and 0.00054m³/day, while the hydraulic and recharge parameter estimated with Modular Three-Dimensional Finite Difference ground water flow model were 0.00055m/day and 2.27520m³/day, respectively

Conclusion: The developed model for the selected parts of Port- Harcourt and Obi-Akpo has low sensitivity values compared with the estimated initial values for the hydraulic conductivity and recharge. Results generated from the model cannot be used to predict future recharge and drawdown for the studied domain area but can serve as baseline for further studies.

Keywords: [Groundwater, aquifer, transmissivity, storativity, specific yield,MODFLOW, Port Harcourt}

1. INTRODUCTION

According to the Stockholm environmental institute, one-third of the world's population already live in areas that suffer moderate to severe water shortages. It was observed that in the cities of the developing countries, their state of water provision and expansion of water project does not meet the required demand. Majority of people in new urban centre of developing countries do not have access to portable water, which is considered in developed countries to be a necessity. The provision of adequate water will go a long way in preventing water-related diseases such as cholera and dracunculiasis. Port Harcourt, water supply is a serious problem which its scarcity has left many people with poor or no access to portable water for domestic and industrial use [1,2].

Groundwater is a very important resource that supplies portable water for both industrial and domestic uses. The known surface bodies of water in the area such as rivers, lakes spring etc are severely polluted by the direct and in-direct discharge of domestic and industrial waste, and this results into larger percentage of the population of the area now solely depending on groundwater as their source of water. Thus, making groundwater resources management a very important tools to survival in Port Harcourt and environ [3,4]

The study of groundwater flow helps to increase the knowledge of the groundwater system, aquifer interaction and accomplishment of proper management of their resources. Groundwater management and modelling addresses and solves a various questions and problems from hydro-geological practice [5]. In recent years, the ability to simulate and predict groundwater flow models have been enhanced by the development methods representing the effects of external hydraulic influences on heads and flow patterns of groundwater systems due to changes in climatic conditions, increase in population size and advancement in civilizations. The rate at which groundwater resources potential decrease compare to water supply demand is very alarming [6, 7].

The study area inhabits lot of companies and industries especially in the oil and gas sector; these have led to the continuous influx of associate companies and people into the area, whose activities have led to the contamination and pollution of the available surface water resources by the discharge of effluents or pollutants in the runoff into the surface water. In regions with economically important resources like Port Harcourt and its environs, it will be helpful to use existing techniques to describe the hydraulic interaction between a borehole and its surrounding aquifer to determine the effect of changes in its water body.

Consequently, there had been an increased demand for portable and sustainable water supply in the area. Future success on the behaviour and prediction of groundwater system within a basin will be determined on continuous availability of data and improve methods for quantifying heterogeneity in subsurface hydraulic properties, enhanced modelling tools and understanding of model uncertainty.

Brief Description of the Study Area

Port Harcourt is located within the Eastern Lower Niger Delta in South Eastern part of Rivers State of Nigeria. It is an urban city with a population of about 1.2 million people (Brinkhoff, 2010). It is located at the right bank of the Bonny River approximately 65km (40 miles) in-land from the Bight of Bonny. Figure 1 shows the Basemap for the study Area. Climate is tropical monsoon and flooding is reported to be frequent. Port Harcourt is bordered on the East and West by oblique Creeks;on the South by first the block yard creeks,then the Bonny River and

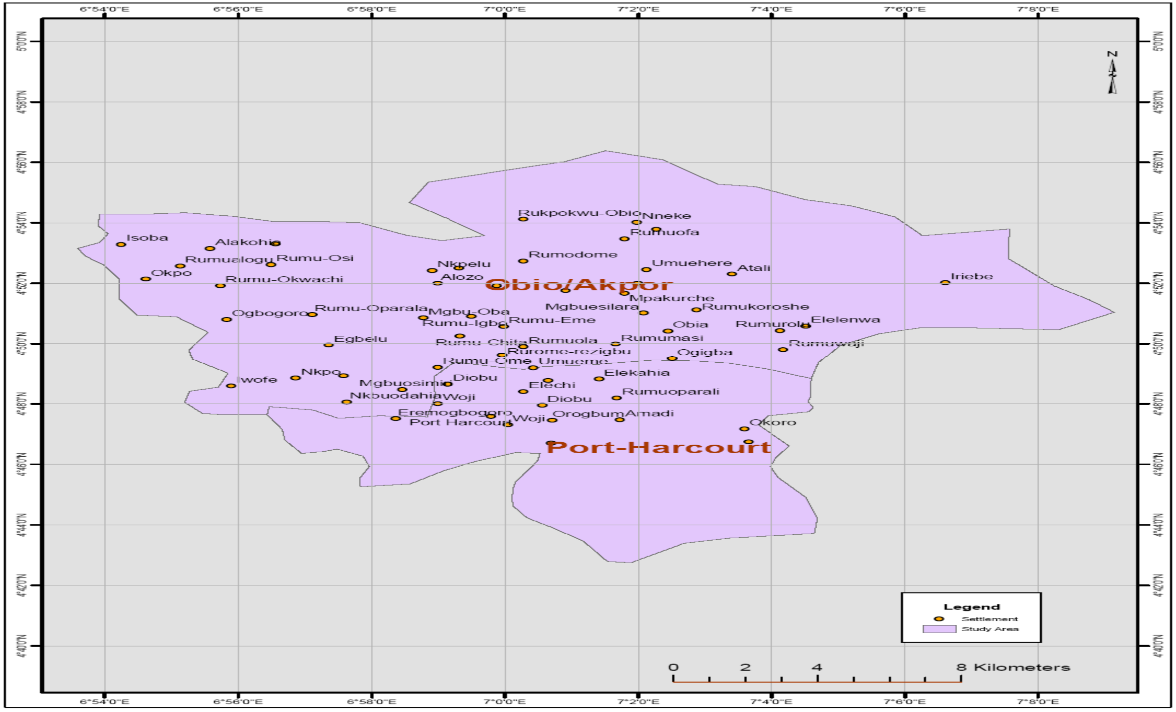

Fig. 1.Basemap for the Study Area

and finally mangrove swamps and on the North by Abia State. The Southern part of the town stands largely on raised levees with silts and clay foundation. These afford dry and firm points within the zone of its fresh water swamps of the Niger Delta. It covers an area of 290sq.km.The boundary of the Port-Harcourt and Obio/Akpor Local Government Areas (LGAs) are assumed to be consistent with the physical natural boundaries. The main city of Port Harcourt is the Port Harcourt Township in the Port Harcourt City Local Government

Area, consisting of the former European quarters now called old Government Reservation Area (GRA) and new layout areas [10,11].

The Port Harcourt Urban Area is made up of the city itself and parts of Obio/Akpor Local Government Area. Port Harcourt City, which is the capital of Rivers State, is highly populated as it is the only major city in the state. A law has recently been passed by the Rivers State House of Assembly to develop the city surrounding communities as part of efforts to decongest Port Harcourt. The Greater Port Harcourt City, spans eight LGAs, which includes: Port-Harcourt, Okrika, Obio/Akpor, Ikwerre, Oyigbo, Ogu/Bolo, Tai and Eleme.Port Harcourt features a climate with lengthy and heavy rainy seasons and very short dry seasons. Only the months of December and January truly qualify as dry season months in the city. The Harmattan, which climatically influences many cities in West Africa, is less pronounced in Port Harcourt. Port Harcourt's highest precipitation occurs during September with an average of 370 mm of rain. December, on average, is the driest month of the year; with an average rainfall of 20 mm. Temperature throughout the year in the city is almost constant, showing little variation throughout the course of the year. Average temperatures are typically between 25°c and 28°c, in the city [11,12,13].

2. METHODOLOGY

Groundwater flow modelling studies require realistic initial data. This data's includes meteorological (precipitation, evapotranspiration and temperature), and flow rates for the borehole logs to identify subsurface profiles. However, groundwater table elevations were not available and therefore field work was undertaken to measure the groundwater head in the aquifer. The main goal was to find accessible wells that could be used to measure the water table elevation. A fairly homogeneous spatial distribution of these monitoring wells was also accomplished. The coordinates of every potential monitoring well were recorded with a GPS device. All potential monitoring wells were tabulated and a short-list of the wells with adequate hydraulic parameters was selected. All relevant properties of these selected 39 monitoring wells were then put into a database

The depth to the water table in each monitoring well was measured using a 150m length electrical tape water level meter which has a CCTV camera at the tip. With the aid of the camera it was possible to see when the tape contacted water. The distance downwards to the water table was then recorded. Groundwater elevations, also called the static water levels were computed by subtracting the measured groundwater depth from the ground elevation. The geological properties in the study area were observed and recorded to verify the degree of accuracy of the geological map. The original geological map was revised accordingly to match field observations.

Modelling Approach

Groundwater Flow Model Setup and Execution

The groundwater flow equations constituting the groundwater flow model of the model domain were solved using the Groundwater Modelling System (GMS) that has been based on the Finite Difference Method (FDM). The groundwater flow model was set up as a one-layered, steady-state model. The purpose of the model was to simulate groundwater flow in the unconfined aquifer, and thereby calculate the distribution of water table elevations and groundwater fluxes. The extent of the modelling domain was the same as the extent of the study area boundaries. The boundaries of the model were determined such that it encompasses the entire area of interest and coincides with hydrological boundaries.

Groundwater Flow Model Conceptualization

A conceptual model for the study area and the aquifer domains was carefully developed. The conceptual model was composed of a set of assumptions that reduced the real problem and the real domains to simplified versions of reality to present the real and Model. These include:

(i) the type of material comprising the aquifer
(ii) the mode of flow in the aquifer, the relevant state variables, area, or volume, over which the averages of such variables were taken;
(iii) sources and sinks of water within the domain and on its boundaries
(iv) the conditions on the boundaries of the considered domain that expressed the way the latter interacted with its surrounding.

The boundaries to the project area were extracted from the digitized map of Rivers State, Nigeria, on a scale of 1:1,000,000, as compiled by Konsadem Associates, Ibadan. The areal extent of the conceptualized domain covers a land distance of about 9,000m on the X -axis and about 12,500m on the Y- axis. Figure 2 a and b depict the boundaries of the study area.

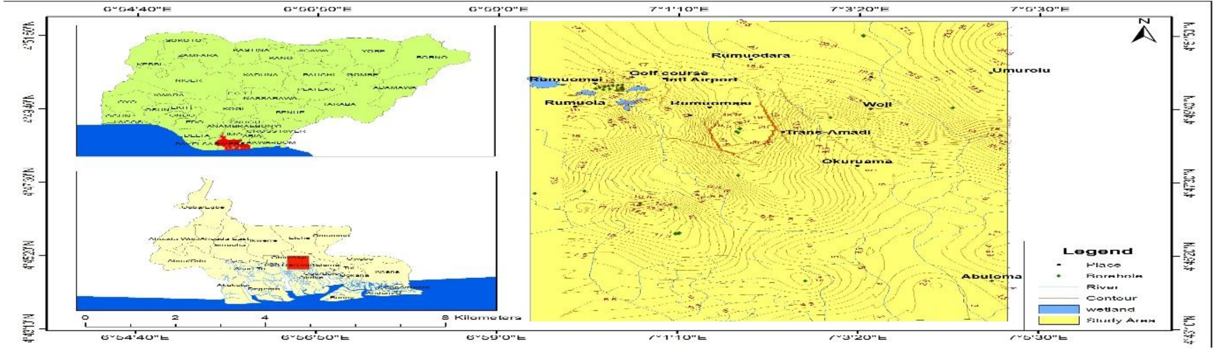

Fig 2a. Contour Map of Domain of Interest with Borehole Locations

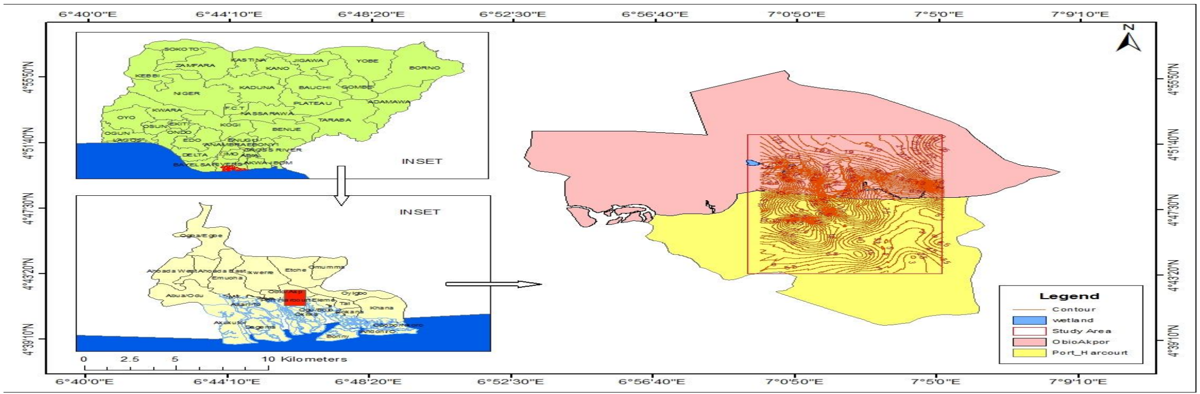

Fig 2b. Problem Domain with Wetland and Conceptualized Profile of Top Layer of Aquifer

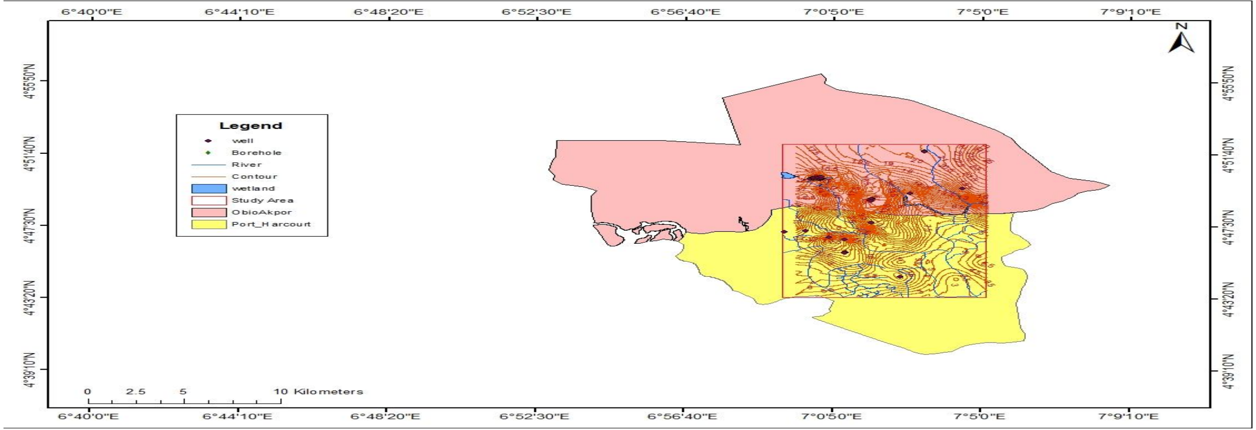

Fig 2c: Conceptualized Form of the Problem Domain with Boundary Conditions

The modelling domain was discretized into mesh-sized 1240 × 1850m finite difference three-layer unconfined grid cells. More than 38 borehole logs were processed to determine the depth to the impermeable layer, which were subsequently interpolated to obtain the surface representing the bottom surface of the model layer. The top surface of the model was obtained directly from the topographic map. Details about the boundary conditions and the spatial discretization of the model were conceptualized. In the modelling exercise, only the topmost layer was modelled because only two boreholes penetrated the second layer while none penetrated the third layer.

The predominantly Benin Formation is idealized as a water table aquifer with an average bottom elevation of 90m below sea level. The aquifer problem domain was discretized into a finite difference grid of 100 rows and 100 columns, with the origin at the bottom left corner. The simplicity is in line with modelling with paucity of data, as contained in [2]. In the passage from the real system to the conceptual model, and then to the mathematical one, for each of the domains, various transmissivity and storage of the extensive quantities such as: the permeability of aquifer medium; aquifer transmissivity, and aquifer storativity, were considered. The method used was the finite-difference method, wherein the continuous system described by the mathematical equations were replaced by a finite set of discrete points in space and time, and the partial derivatives were replaced by terms calculated from the differences in head values at these points. The process led to systems of simultaneous linear algebraic difference equations, with their solution yielding values of head at specific points and transient. These values constituted an approximation to the time-varying head distribution that would be given by an analytical solution of the partial-differential equation of flow.

The model handled discretization of space in the horizontal direction by analyzing the number of rows, the number of columns and the width of each row and column (that is, the width of the cells in the direction transverse to the row or column). Discretization of space in the vertical direction was handled in the model by specifying the number of layers to be used, and by specifying hydraulic parameters which contained or embodied the layer thickness. The model equations were based on the assumption that hydraulic properties were uniform within individual cells, or at least that meaningful average or integrated parameters could be specified for each cell. The approaches to vertical discretization described above all led to a set of mathematical equations, which were solved simultaneously at Steady state. The numerical values of all the relevant coefficients and state variables were obtained from data collected from: the Federal Ministry of Water Resources on Hydrogeological Investigation of the Eastern part of Nigeria; MessrsBadafash Nigeria Limited on Borehole Data Inventory and Pumping Test Analyses for Groundwater Development in Nigeria; Konsadem Associates Consulting Engineers, and the published literatures.

Using these data as initial conditions for a problem domain, a numerical simulation based on the mathematical model so developed, was carried out sequentially as follows:

(i) The known initial conditions were imposed on the model.

(ii) The model was excited by the known excitations of the real system.

(iii) The response of the model was derived from these excitations.

To derive the model’s response, some trial values of the sought coefficients (aquifer permeability, transmissivity and storativity) were assumed, based on field data, obtained from published literature. The response so observed in the real system with that predicted by the model was thereafter compared. The sought values of the coefficients were taken as those that eventually made the two sets of state variables identical.

Governing Equation

The equation for the three-dimensional flow of groundwater with constant density through the study area was described by the partial-differential equation in equation 1:

$$\frac{\partial}{\partial x}\left\{Kxx\frac{\partial h}{\partial x}\right\} + \frac{\partial}{\partial y}\left\{Kyy\frac{\partial h}{\partial y}\right\} + \frac{\partial}{\partial z}\left\{Kzz\frac{\partial h}{\partial z}\right\} - W = Ss\frac{\partial h}{\partial t} \qquad (1)$$

where:

K_{xx}, K_{yy} and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axis, which are assumed to be parallel to the major axis of hydraulic conductivity (LT^{1});
h is the potentiometric head (L);
W is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1});
S_s is the specific storage of the porous material (L^{-1}); and
t is time (T).

In general, S_s, K_{xx}, K_{yy} and K_{zz} are functions of space (S_s = Ss (x, y,z), K_{xx} = K_{xx}(x,y,z), K_{yy} = Kyy(x, y,z) and K_{zz} = K_{zz}(x,y,z)) and W is a function of space and time (W = W(x,y,z,t)).

Equation (1) describes the flow of groundwater within a non-equilibrium condition, provided the principal axes of hydraulic conductivity are aligned with the coordinate directions. The Equation above with the specification of flow at the boundaries of the aquifer system and other parameters constitute a mathematical representation of the Port Harcourt and Obiakpo L.G.A groundwater flow system.

Groundwater Flow Models

Numerical groundwater flow models of Port Harcourt and Obiakpo L.G.Adomains were developed to better understand the aquifer system of the study area and to determine the long-term availability of groundwater by simulating groundwater conditions resulting from historical pumpage in the distant seventies, representing period of pre-development in the aquifer basin, The models were developed using assumptions and approximations to make simpler the actual aquifer system. The models idealized the compound hydrogeologic relations of the actual system based upon the data and the assumptions used to develop it.

The USGS Modular Three-Dimensional Finite-Difference Ground-Water Flow Model (MODFLOW), simplified by the Groundwater Modelling System, developed by AQUAVEO, was used to simulate flow in the aquifer domains within the study area. The ground-water flow system in the aquifer domains were numerically defined by discretizing the aquifer system into finite difference grids, determining the boundary conditions for the aquifers, estimating the rates and distribution of recharge and discharge in each case, and estimating the aquifer properties within the models. To simulate past conditions, steady-state (predevelopment) was derived and calibrated. Results of the steady-state simulation was used as initial conditions for the transient-state model in future groundwater research in the aquifer domain. This is outside the scope of the present work.

Aquifer Properties

Aquifer properties, such as hydraulic conductivity, transmissivity, specific yield, and storage coefficient, control the rate at which water moves through the aquifer, the volume of water in storage, and the rate and areal extent of water-level declines caused by ground-water development. The aquifer system properties across the study area were initially estimated from well logs, specific capacity tests and the published literature. The initial values of horizontal hydraulic conductivity and recharge were 3.3785mm/day and 0.0000451m/day, respectively, while the final values after adjusting the parameters to obtain a good match between observed and computed hydraulic heads, were 2.2752mm/day and 0.000549m/day, respectively. Final estimates of these properties were made using a trial-and-error approach during steady state model simulations. The aquifer property values could vary considerably spatially because of the heterogeneity of the aquifer system material.

Selection of Observation Wells

A total number of 149 boreholes were collected from the model area. Several gaps exist within these borehole records. The reasons being, since the records were not government official/approved published data, and also because each of the borehole drillers had different benchmarks of referencing their measured data. Converting all the obtained data to assume the same reference points with respect to elevation was an arduous task. At the end of processing, 38 boreholes, with realistic hydraulic data, were selected for the groundwater modelling exercise. A total of eleven observation wells were used in the model calibration of the aquifer domain. The sampled 38 boreholes with the hydraulic parameters are presented in Table 1. The hydraulic parameters have been assumed to have zones of coverage area within the entire boundary of the model domain.

Ground-water pumpage is the main discharge from the basin. Ground-water pumpage in the study area began during the colonial era, in the fifties. There was, however, no record of daily, monthly or yearly groundwater pumpage for the entire study area. The distribution of pumpage for the simulation exercise was therefore estimated as a percentage of water based on well-capacity data from pumping tests

Model Calibration and Sensitivity

Each ground-water flow model of the aquifer model domains was calibrated using a trial-and-error method in adjusting initial estimates of aquifer properties, such as recharge and hydraulic conductivity to get a best match between simulated hydraulic heads and measured water levels, and selected water-budget items. The initial estimates for the aquifer properties were based on the geologic and hydrologic properties of the study area. These estimates were used in a steady-state simulation to provide initial conditions for a futuristic transient-state simulation, which is beyond the scope of this work. The aquiferous model is sensitive to recharge and hydraulic conductivity.

Steady-state flow conditions exist when inflow is equal to outflow, and aquifer storage does not change with time. Ground-water conditions in the seventies (assumed to represent pre-development conditions) were used to calibrate the steady-state model. These assumptions are similar to the ones obtained in [2 and 3]. The Mean Error (ME) and Root Mean Square Error (RMSE) were using equation 2 and 3

$$\mathrm{ME} = \sum_{n=1}^{N} X_J \,/\mathrm{N} \qquad (2)$$

where$X_j = a_j - b_j$ (2a)

X_j = residual head obtained after calibration.

a_j = observed head.

b_j= simulated head.

N = number of observation wells used for the calibration process.

The Root Mean Square Error (RMSE) for the calibration process was computed using equation 3:

$$\mathrm{RMSE} = \left(\sum_{n=1}^{N} X_J{}^2 \,/\mathrm{N}\right)^{0.5} \qquad (3)$$

Many assumptions and estimates were used in the design and construction of the Port Harcourt/Obiakpo Alluvium ground-water flow models. To test the response of the calibrated models to a range of values for the initial hydraulic properties, a sensitivity analysis was carried out. This was done by varying the value of one input parameter while keeping all others constant. From this analysis, it was possible to observe the relative sensitivity of the model to various input properties. Thus, separate model simulations were made with varied input properties, and the changes in simulated hydraulic heads and in components of the water budgets were observed. The Linear Regression Formula as outlined by [13] was used to compute the regression equation and the coefficient of correlation (r) for each of the aquifer domains is expressed as equation 4.

$$r = \frac{\mathrm{N}\,(\sum \mathrm{XY}) - (\sum \mathrm{X})\,(\sum \mathrm{Y})}{\sqrt{[\{\mathrm{N}\sum \mathrm{X2} - (\sum \mathrm{X})2\}\{\mathrm{N}\sum \mathrm{Y2} - (\sum \mathrm{Y})2\}]}} \qquad (4)$$

Where:

Y = calculated or simulated head (m); X = observed head (m); A is the constant term of regression and B is the regression coefficient, N= number of records of data.

The Plot Wizard in Ground Water Modelling System (GMS), 10.0.6 Version was used in extracting data from the calibrated model for model verification. A computed versus observed hydraulic heads was used to display how well the entire set of observed values matched the calibrated model solution. A computed versus observed weighted plot was used to display how well the entire set of weighted observed values matched a model solution. These weights were set by selecting the observation item in the MODFLOW. A residual versus observed plot was also used to investigate the calibrated model. A residual versus observed (weighted) plot was used to display how well the entire set of weighted observed values matched the model solution. An error versus simulation plot was used with the steady state simulation and measurement types to display the mean error, mean absolute error, and root mean squared error between successive solutions and observed data. Several simulations were run after changing model parameters, such as hydraulic conductivity or recharge. These plots showed trends in the solution to see if model parameter was causing better calibration with measured field data. The flow budget displayed the flow of water over time for selected grid cells. The Flow budget was computed either from the zone budget identities.

3. RESULTS AND DISCUSSION

Matching the initial heads obtained for the aquifer with the hydraulic heads simulated by MODFLOW in a Steady State Calibration. It was done by sequential adjustment of the model parameters such as hydraulic conductivity, boundary conditions and recharge. The summary of initial and final hydraulic parameter estimates for the ground water flow model domain are tabulated in Table 1. The procedure for deriving the final hydraulic parameters is consistent with the approach adopted by [1, 2]

Natural recharge in the aquifer domain was mainly due to infiltration of precipitation runoff within the Alluvium drainage basin. The initial estimate of natural recharge from precipitation runoff used to calibrate the steady state models was $5.49\mathrm{x}10^{-4}$ m/day. This estimate was increased to about 2.2572 mm/day during calibration of steady state simulations. No record of pumpage exists for the study area. Therefore, the distribution of pumpage for the entire modelling exercise was estimated as a percentage of water based on well-capacity data from pumping tests of boreholes. No evidence of previous numerical groundwater simulation exercise was however found within the project coverage area.

Table 1: Initial and Final Hydraulic Parameter estimate for Groundwater Flow Model Domain

S/No	Aquifer Parameter	Alluvium Formation	Alluvium Formation
		Initial Parameter (M/Day)	Final Parameter (M/Day)
1	Hydraulic Conductivity	0.0000451	0.000549
2	Recharge	0.000549	2.2752

For this study, pumpage estimated from borehole records from The Federal Ministry of Water Resources (FMWR), Konsadem Associates and OSOT Associates Consulting Engineers, Ibadan, was reliably adopted.

Calibration Target for the Model Domain

The steady state calibrated model of the Port Harcourt/Obiokor domain is presented in Table 2. A calibration target was drawn next to the eleven (11) observation wells. The components of a calibration are illustrated in Figure 3. The centre of the target corresponds to the observed value. The top of the target corresponds to the observed value plus the interval and the bottom corresponds to observed value minus the interval. The coloured bar represents the error. The coloured bar is drawn in green for all cases where the bar lies entirely within the target. If the bar is outside the target, but the error is less than 200%, the bar is drawn in yellow. If the error is greater than 200%, the bar is drawn in red. Three (3) of the examination wells, matched the computed heads within the calibration target limit, while one (1) well fell outside the target, but was within 200% of the observed value. Seven (7) wells were completely outside the specified range. The analyses of the results, in general, portrays the degree of reliability of the calibrated model to duplicate reality.

The correlation graphsin this study are presented in Figures 4. – 8. The points located above the correlation line indicated an over-estimation of simulated water level heads at the corresponding observation wells, with discrepancies equal to the vertical difference between the coordinate and the correlation line. However, points located below the correlation line indicate an under-estimation of simulated hydraulic heads at the corresponding observation wells. The vertical difference between the points and the 1:1 correlation line depicts the degree of underestimation.

Table 2: Calibrated Target of Eleven Observation Well

S/NO	X (m)	Y (m)	Head (m)	Interval (m)	Confidence (%)
Obs #1	284420.0	537950.0	92.0	1.5	95
Obs #2	278980.0	534910.0	84.0	1.5	95
Obs #3	286450.0	533980.0	91.0	1.5	95
Obs #4	281650.0	532810.0	55.0	1.5	95
Obs #5	281720.0	530310.0	51.0	1.5	95
Obs #6	279280.0	529470.0	37.0	1.5	95
Obs #7	278220.0	529270.0	34.0	1.5	95
Obs #8	279520.0	528770.0	27.0	1.5	95
Obs #9	280320.0	528470.0	17.0	1.5	95
Obs #10	280380.0	527110.0	15.0	1.5	95
Obs #11	283190.0	524540.0	14.0	1.5	95

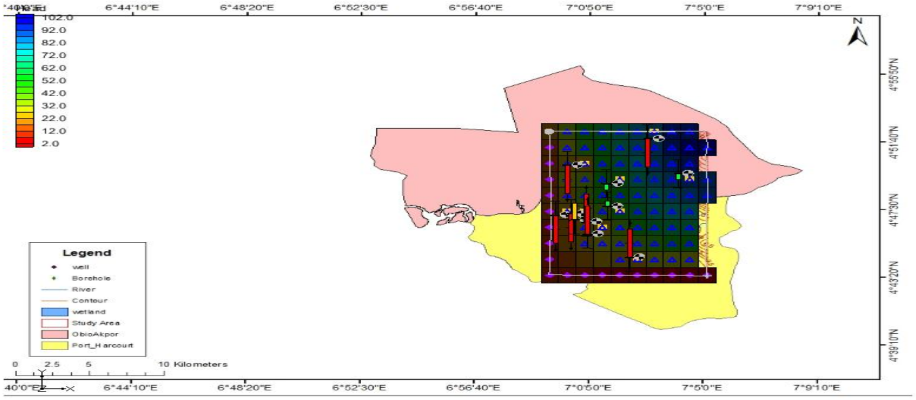

Fig 3. Steady State Calibrated Model of the Port Harcourt/Obiokor Domain

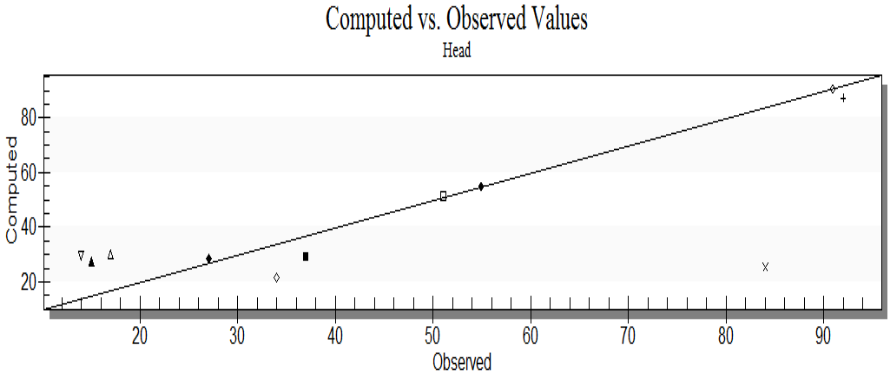

Fig 4. Ratio 1:1 Line of Computed and Observed Heads for the Model Domain

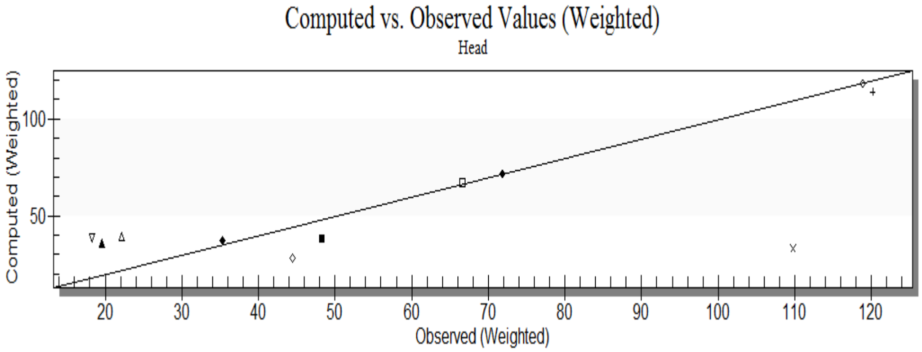

Fig. 5. Ratio 1:1 Line of Weighted Computed and Observed Heads for the Domain

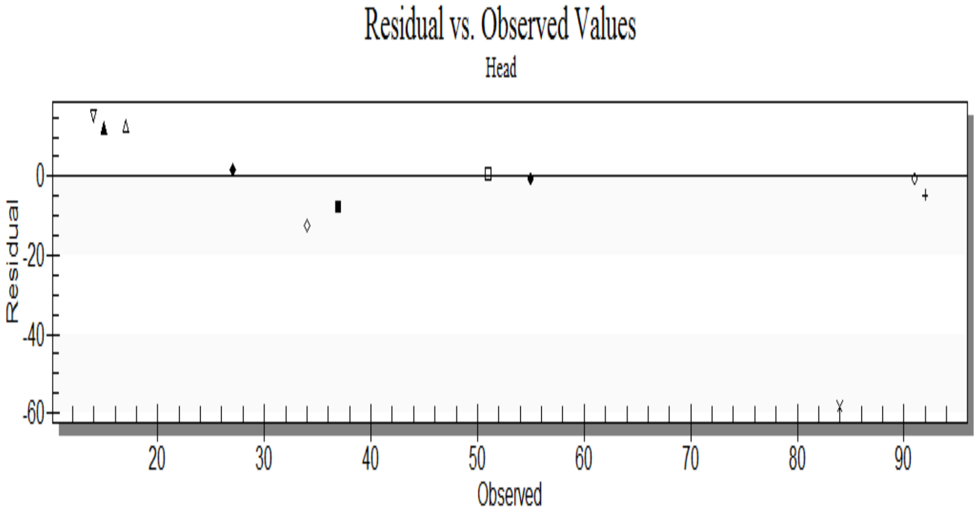

Fig. 6. Plot of Residual versus Observed Values for the Model Domain

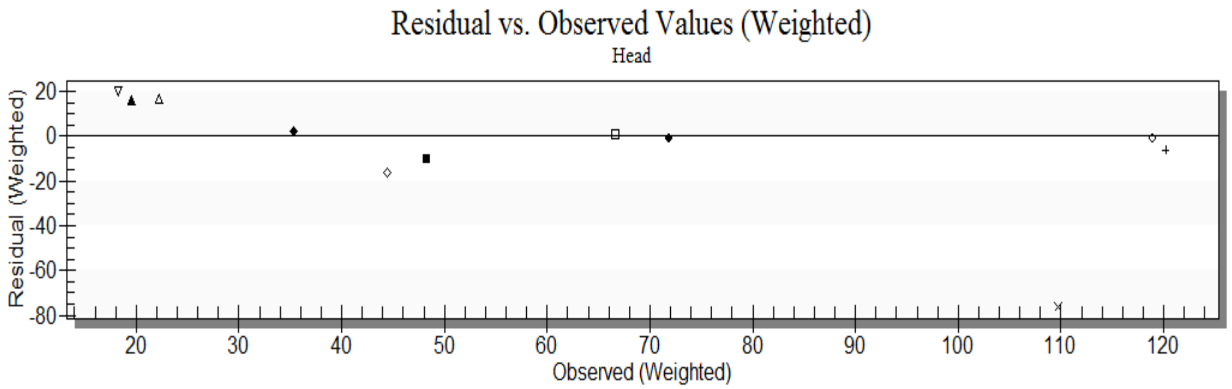

Fig. 7. Plot of Weighted Residual versus Observed Values for the Model Domain

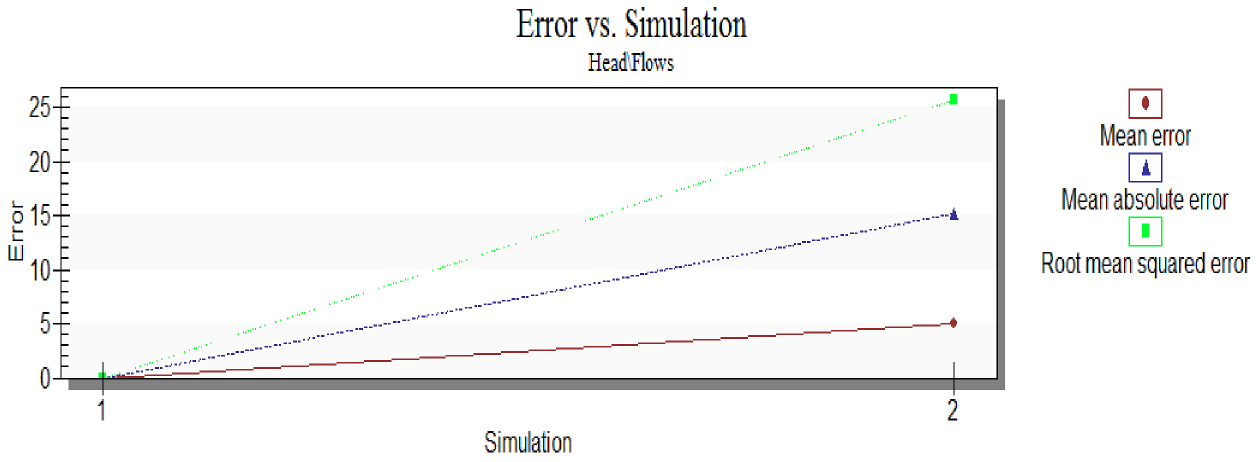

Fig. 8. Plot of Error versus Simulation for the Model Domain

The procedure adopted is in line with similar numerical modelling analyses carried out by [2, 3 and 14].The Residual versus Observed plot is presented in Figure 6 which shows how well the entire set of observed values matched the model solution. On this plot is drawn a horizontal line along an error of zero, indicating what would be a perfect correspondence between observed data and solution values. One symbol is drawn for each inspection point at the intersection of the observed and residual (computed-observed) values for the point.The Error versus Simulation plot shown in Figure 8 that shows the Mean, Mean absolute, and Root mean squared error between successive solutions and observed data. Various simulations were run after changing model parameters such as hydraulic conductivity or recharge. The plot shows trends in the solution to present if model parameter changes were causing better calibration with measured field data.The differences, outside calibration target, between simulated and measured values were perhaps due to an inaccurate distribution of pumpage to the individual wells, an inaccurate estimation of the quantity and distribution of natural recharge, and/or inaccuracies in the reported water-level measurements.

The simulated water budgets at the end of the calibrated steady-state simulations were used to describe the flow characteristics in the domain. The water budgets of inflow (recharge to) and outflow (discharge from) in the aquifer model domain are shown in Table 3.

Table 3: Water Budget of Inflow and Outflow in the Aquifer Model Domain

Sources/Sinks	**IN**	**OUT**
CONSTANT HEAD	0.0	-53079.84924316
WELLS	0.0	-34261.70361328
RECHARGE	87341.555786133	0.0
Total Source/Sink	87341.555786133	-87341.55285645
Zone Flow		
FLOW RIGHT FACE	0.0	0.0
FLOW FRONT FACE	0.0	0.0
FLOW LEFT FACE	0.0	0.0
FLOW BACK FACE	0.0	0.0
Total Zone Flow	0.0	0.0
TOTAL FLOW	87341.555786133	-87341.55285645
Summary:	In	Out (% difference)
Sources/Sinks	0.0029296875	3.35428826e-006
Cell to Cell	0.0	0.0
Total	0.0029296875	3.35428826e-006
Flow Budget for Zone 1		
CONSTANT HEAD	0.0	53079.849243164
WELLS	0.0	34261.703613281
RECHARGE	87341.555786133	0.0
Total	87341.555786133	87341.552856445
SUMMARY:		
IN - OUT	0.0029296875	
Percent Discrepancy	3.35428826e-006	

4. CONCLUSION

The following conclusions were drawn from this study

(i) The Port Harcourt/Obiokor Alluvium model was numerically simulated using GMS 10.0.6 software. The aquiferous formation holds great potentials for groundwater storage and exploration in the locality.

(ii) After steady state calibration in the Alluvium Aquifer Formation, the simulated hydraulic heads were at varying distances to the calibration target, with four of the observation wells falling within acceptable limits and seven outside the limits. The quality of the available data cannot be used to model beyond the preliminary investigation of groundwater flow within the aquifer domain.

(iii) During steady-state calibration in the Alluvium Aquifer Formation, the hydraulic conductivity and the recharge were positively adjusted until computed heads fell reasonably close to the observed heads in a matching exercise. This scenario indicated that there is an abundance of groundwater reserve in the aquiferous formation

RECOMMENDATION FROM THE STUDY

The following recommendations were reached from this present study

(i) In the future, with additional data, further refinement of the model could be possible, which could improve the accuracy of the model forecast of the effects of additional stresses on the aquifer system.

(ii) The Federal government should encourage the updating of borehole data all over the federation, with a view to having government published data, which would be useful for investigation and management of the nation's groundwater resources.

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